

A NEW TWO-WAY TIME TRANSFER MODEM

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Abstract

The use of commercial communications satellites for precise time transfer has been performed with a variety of techniques for a number of years. Military communications systems can also provide this function in a few deployed systems. This paper will describe a new design of a time transfer modem that can be produced at a reasonable cost and enable users to make direct comparisons with the Naval Observatory with nanosecond precision. A flexible, all-digital design is being implemented that will enable a variety of different codes to be employed. Compatibility with existing equipment, such as the HARTL Modem, is a goal of this development. The design and operating modes of this equipment will be described.

INTRODUCTION

The United States Naval Observatory (USNO) routinely makes two-way time transfers through the Defense Satellite Communications System (DSCS). An interface with the system's spread-spectrum communications modems is used to provide a precise-time trunk line for interests located near the DSCS terminals. For a link with no communications modem, spread-spectrum time-transfer modems designed by the Naval Research Laboratory (NRL) were used. NRL is developing a modem that will work with very small aperture terminals and commercial satellites to serve other users requiring greater accuracy.

DESIGN APPROACH

A two-way spread-spectrum method (Figure 1) will be used because of its performance and its insensitivity to positions of receivers and satellites. Digital hardware is used in the modem design as much as possible to meet requirements for accuracy, long-term stability and versatility. The digital techniques also meet requirements for reliability and cost. The modem is being designed for maximum compatibility with other time transfer systems. Off-the-shelf equipment will be combined with some special purpose hardware. The off-the-shelf parts will include the satellite terminal (VSAT), the Personal Computer (PC) and the Digital Signal Processor (DSP) card. Items of special equipment will be an analog box and a digital board (Figure 2).

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE NOV 1989		2. REPORT TYPE		3. DATES COVERED 00-00-1989 to 00-00-1989	
4. TITLE AND SUBTITLE A New Two-Way Time Transfer Modem				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory, 4555 Overlook Avenue SW, Washington, DC, 20375				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES See also ADA224769. Proceedings of the Twenty-first Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, Redondo Beach, CA, 28-30 Nov 1989					
14. ABSTRACT see report					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 7	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

To avoid drift of analog circuits, the received signal will be digitized at as high a frequency as possible, 25 million samples per second (Figure 3). All processing after this point will use digital signal processing methods. The faster functions will be done with the dedicated special digital board hardware (Figure 4), and the slower phases with the programmable DSP card.

For versatility, a numerically controlled oscillator (NCO) will be used to generate a programmable code rate. For code selection a code generator chip with programmable taps will be used. The combination of an NCO and a programmable code generator give almost unlimited possibilities in code generation. It will be easy to generate a code compatible with the Hartl Mitrex modem or the Global Positioning System (GPS) clear/acquisition (C/A) code.

Under some conditions, problems arise in using digital method due to time quantization in the sampling of the data. It is possible by adding random noise at appropriate places in the processing to improve the time resolution of the measurements beyond a small fraction of the sampling period.

A 32-bit floating-point DSP will be used as the microprocessor. This DSP will be a commercial card that will plug into the PC backplane. The DSP systems are very fast, over 10 Million Floating Point Operations per Second (MFLOPS), and have C compilers. This will give expansion capabilities and make software development easier. The DSP system will configure the system hardware, control acquisition and tracking of the signals, demodulate and format the data on the received signal, make the range measurements, process the range measurements into time transfer information and control all communications functions with the PC.

All operator controls other than VSAT controls, power levels, frequency selection and antenna pointing, will be handled by the PC. In the communication mode, files will be transferred between the PCs of the participating stations.

SIGNAL STRUCTURE

The modem, which is under software control, can accommodate a wide variety of signal structures. For the planned bandwidth of about 3 MHz, binary phase shift keying (BPSK) will be used with a chipping rate in the order of 2 Mb/s. (It can easily be changed for compatibility with other systems). A 4095-bit maximal-length sequence is currently planned. To produce a code length of 1/600 second, a chipping rate of approximately 2.457 Mb/s will be used. The code length is chosen for quick synchronization, while still maintaining a robust capability to recover BPSK data sent at one bit per code cycle. A data rate equal to or at a submultiple of the code cycle rate makes for easier handling, since a part of the computation involves determining after the fact the state (1 or 0) of the previous data bit. (To resolve the PRN code's (1.66... ms) ambiguity, the receiver must recover a time tag having resolution to within a code cycle). From a signal-to-noise standpoint, the channel would support a considerably shorter code and higher data rate, and they might be used eventually, but a shorter code, when not modulated with data, would contain brighter spectral lines spaced farther apart and is currently being avoided.

DATA EXCHANGE FORMAT

No specific data exchange format has yet been adopted. Besides the time tag, which must be transmitted both ways, measurement data must be transmitted at least one way. Other coordination and

identification data are also needed. (Note that all but an unambiguous time tag can be sent via another channel or a different medium). A time tag need be sent only once during a continuous session, but the measurement data are probably best exchanged about once per second. Since one pulse per second is a common output signal for clocks, and measurements will be made by most users with reference to that timing signal, a one-second measurement cycle and time tag seems apt. (Measurements in the NRL receiver will be made over shorter intervals and averaged for the one-second reading). To resolve the ambiguity of the once-per-second time tag, a time-of-day (TOD) message giving hours, minutes and seconds of the day and a day-of-year (DOY) word may be needed by some users. Also of interest to some timekeepers is the date and sign of the next leap second.

The message format could and may be left completely open (except for the time tag). However, the most generally useful information for a timekeeper might be included in a fixed-format segment for efficient transmission without framing delimiters. Optional data may be transmitted during the rest of the second. One possibility for character representation would be 7-bit ASCII plus start and stop bits (a 9-bit asynchronous version) to maintain time-tag integrity. Tables 1a and 1b show a possibility for message formats. (A BCD version which would preserve the integrity of the time tag is also being considered; it is much more efficient in transmitting the numbers in the fixed field and, at 8 bits per character (2 decimal digits), would support all the ASCII characters needed to send numbers, the capital alphabet and all required punctuation).

TABLE 1a. Data Possibilities
600 bit/sec Asynchronous, 9 bits/character, 7-bit ASCII
Data Sent by USNO

Data	Characters	No-Data Characters	Bits	Cum. Bits
TOD	6	ASCII NUL	54	54
Current DOY	3	ASCII NUL	27	81
Leap-Second (DOY+Sign)	4*	ASCII NUL	36	117
Sta. ID + Reply Code #	4	ASCII NUL	36	153
Optional Data	48	ASCII NUL	432	585
Remainder of Second**	Marking	All mark bits	15	600

The structure shown in Table 1 could designate 36 different pseudo-random noise (PRN) reply codes and 1296 different stations using alphanumeric characters. Station 00 might call for no one, while station ZZ might designate a USNO broadcast of general information. A broadcast mode, either for modest-accuracy users or for more detailed information, is easily accommodated.

GENERAL DESCRIPTION OF OPERATIONS

It is expected that USNO would ordinarily operate with one station at a time, but could operate with multiple stations using code-division multiplexing. (Note that USNO need transmit only one PRN code but would receive different codes from the other stations). The identification code of a single user would be sent each second by USNO in the proper slot. However, more stations can be

TABLE 1b
Data Possibilities
600 bit/sec Asynchronous, 9 bits/character, 7-bit ASCII
Data Sent by Remote Stations

Data	Characters	No-Data Characters	Bits 7	Cum. Bits
TOD (hh:mm:ss)	6	ASCII NUL	54	54
Current DOY	3	ASCII NUL	27	81
Leap-Second (DOY+Sign)	4*	ASCII NUL	36	117
Sta. ID	2	ASCII NUL	18	135
Measurement Data	11	ASCII NUL	99	234
Optional Data	39	ASCII NUL	351	585
Remainder of Second**	Marking	All mark bits	15	600

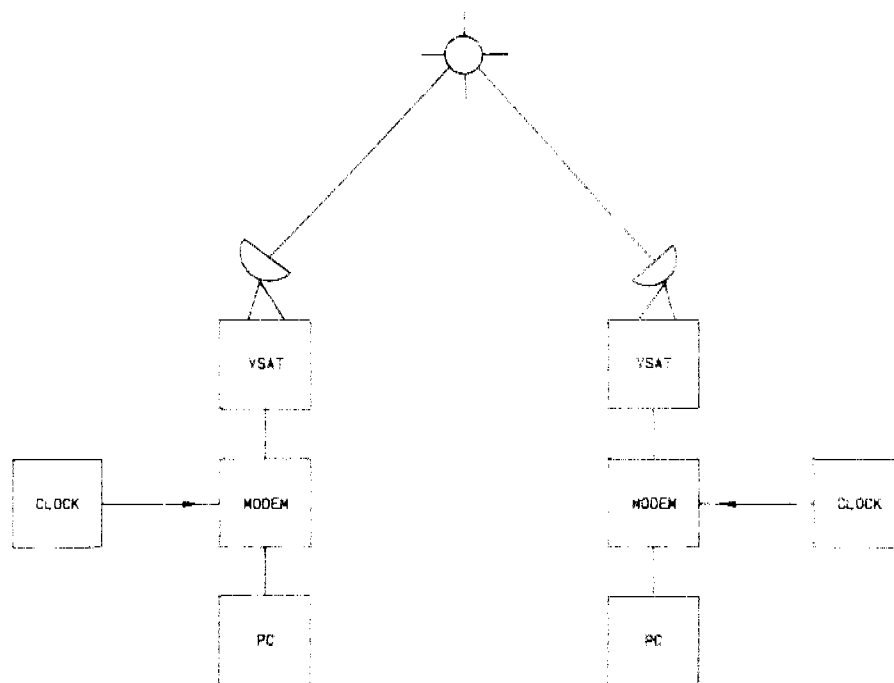
* The entire leap-second information could be represented more compactly by three decimal characters or by 2 alphanumeric characters.

** The first start (space) bit in the TOD message denotes the beginning of the second.

worked by sending their IDs less frequently. To give USNO the required single point of control over the network, a user station would monitor the USNO primary code (continuously or on schedule) and would transmit only while being polled by USNO. If one fails to receive its ID over a pre-established number of seconds, it would stop transmitting and would not come on again until its ID is received at least several times.

a specially designated PRN code might be reserved for user requests for service from USNO, who could then poll the station on the primary USNO transmitting code and specify a reply code. To preserve single-point control, the user must receive USNO on the primary code before initiating a request.

A large increase the communications capability could be had by using additional PRN sequences. With both carrier and code synchronization already established on the primary code, a second code could be received with very little additional complication. The data rate used with the second code need not be related to the code cycle length and might be considerably higher than that of the primary code. There are no current plans to implement this mode in the first model of the modem.

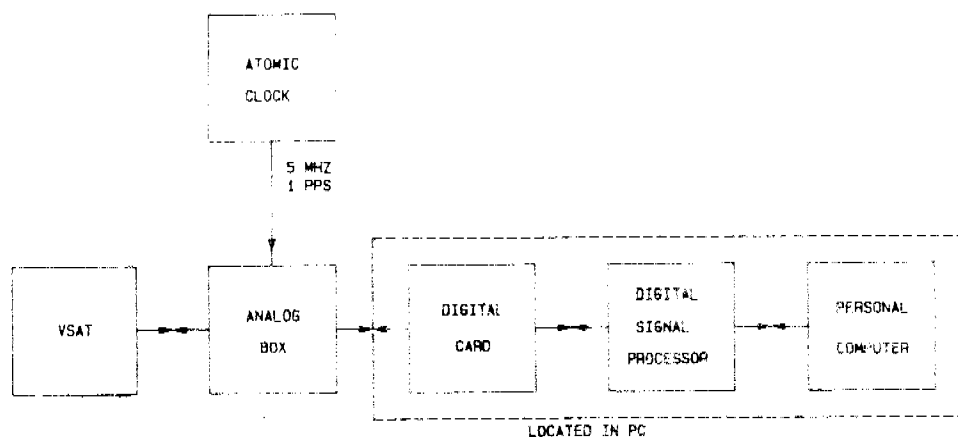


TIME TRANSFER SYSTEM

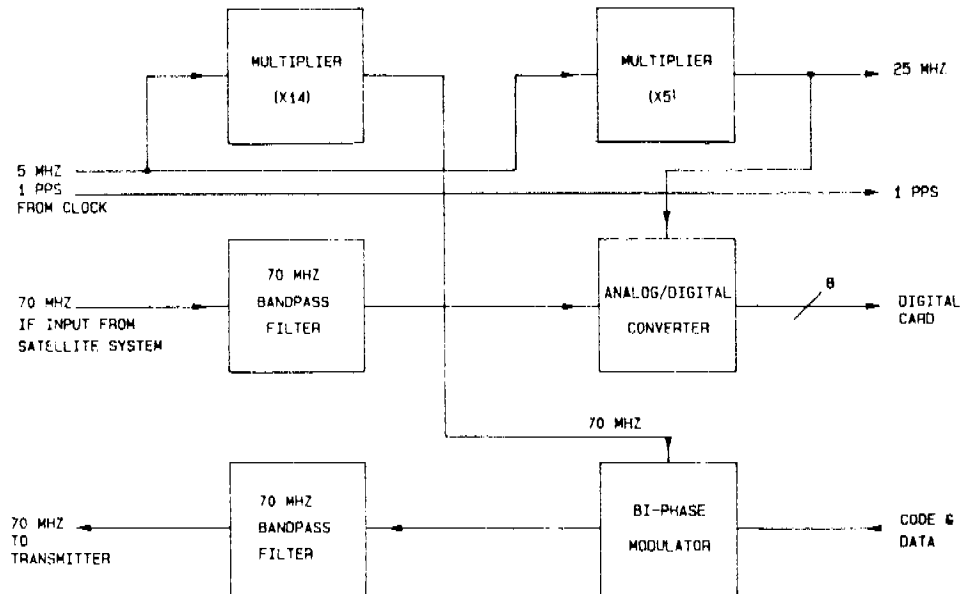
FIGURE # 1

FIGURE # 2

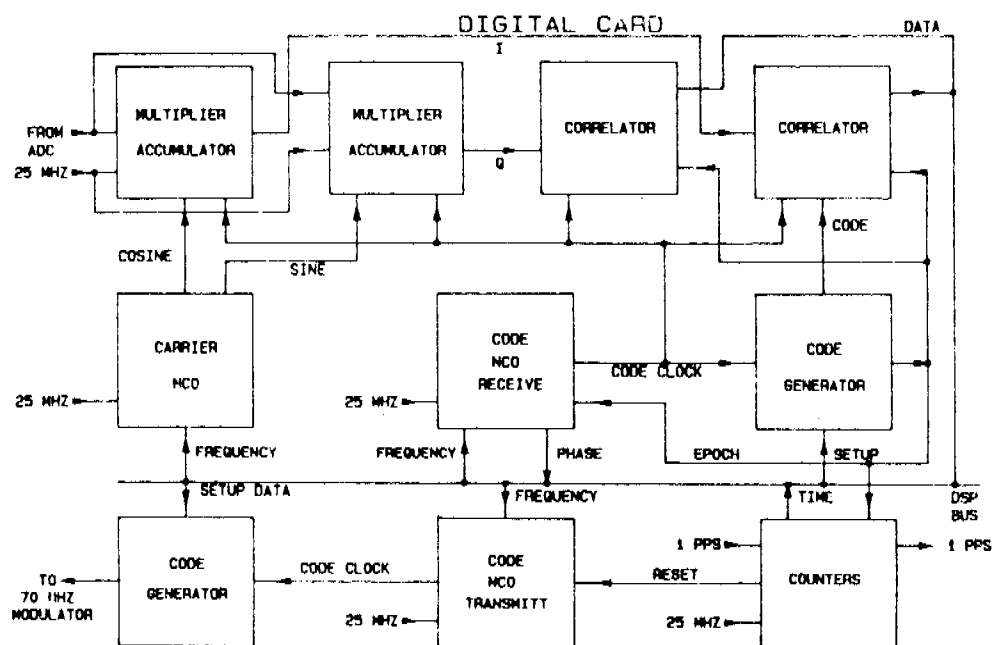
TIME TRANSFER SYSTEM



ANALOG BOX



DIGITAL CARD



QUESTIONS AND ANSWERS

DAVID ALLAN, NIST: what is your time table for this project?

MR. LANDIS: We would like to have it finished within a year. That is the modem part, not the GPS part.